MINI PROJECT REPORT

BIOSENSING AND BIOINSTRUMENTATION BE503

EMG Sensor Design Instrumentation via MATLAB Simulink

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Abstract

With this paper, we aim to study and explore the simulation and fabrication of the surface electromyographic sensor for prosthetic-related device control. Muscle Action triggers the electrical signal in this case the bio-potential signal which leads to the generation of EMG Activity. These signals are used as an input received from several motor points but these are highly adulterated with several intrinsic and extrinsic noises and efforts are put into device several filtering techniques to develop a high signal-to-noise ratio characterized sensor. In this project to simulate several components of a SEMG sensor in the active state, we have developed a novel Simulink model.The EMG signal recorded was from the monopolar needle, Tibialis anterior, and fine wire isometric contraction. The turnout result of the SEMG sensor which is developed is in sync with the stimulated result derived from the model.

Theoretical Background

EMG signal

EMG or also known as electromyography is associated with the study and analysis of skeletal muscle's activity in particular events involving electrical activity. EMG signal is one of the complex signals controlled and regulated by the nerve impulse and is highly manipulated by muscle's anatomy and physiology. One of the distinctive characteristics of EMG signal is that it is noise acquired amidst its travelling among tissues. Different motor units in the body such as skin are used for collecting electrical samples through interaction from EMG detectors. The need of EMG nowadays is irreplaceable in medical engineering; it is one of the major forms of clinical diagnosis in biomedical analysis.
Equation 1 shows a simple model of the EMG signal:

In contrast to the conduction of electrical potential by the nerve to the muscle tissue, Muscle action potential is the term coined for the similar conduction by muscle tissues and the term given to recording of this information(muscle action) potential is called surface EMG. Signal-to-noise ratio and distortion of signal are the two main concerning factors vastly affecting the fidelity of the signal during the times of detecting and also in the process of recording the EMG signal.

Signal-to-noise is the term used to describe the ratio of EMG signals with the noise signal energy considering noise is defined as those electrical signals which are undesired in the extracted EMG signals. When we say Distortion of the signal, we specifically mean the alteration of any frequency component in the signal. For acquiring the signals from the muscles the two electrodes i.e. invasive electrode and the non-invasive electrode have been used. At any one moment EMG signal may be all positive or all negative the reason being that when the signal is acquired it is essentially a composite of all the action potentials from the muscle fibres occuring in the underlying skin. The process of acquiring the individual muscle fibre is implemented by the usage of wire or needle electrodes attached to the muscle directly. The below equation (Equation 1) shows a simple model of the EMG signal.[1]

$$x(n) = \sum_{r=0}^{N-1} h(r)e(n-r) + w(n) \quad (1)$$

where, x(n) is the modeled EMG signal,

e(n) is the point processed, representing the firing impulse,

h(r) is representing the MUAP,

w(n) is the zero mean additive white Gaussian noise

N is the number of motor unit firings.

Electrode picks up the signal and is amplified. The signal before being stored or being displayed is the process intended to get rid of the noises such as low-frequency and high-frequency noises and any other possible artifacts. In order to indicate the EMG amplitude the signal is rectified frequently and averaged out.

The nervous system being the controlling and communicating unit of the body has an accumulation of a vast number of interconnected excitable cells namely neurons which like to transmit the messages amidst the different body parts by means of electrical signals which are very fast paced and with a defined purpose. These neurons are the very fundamental unit of the neural system communicating with each other in forms of impulses.

The collection and composition of specialized cells with the capability of contraction and relaxation make up muscles. Its primary objective is to generate force allowing movements and giving other modes of communication and expression.It is very elastic and can be extended with the ability of receiving and responding to an external stimulus. On the very basis of structure and control mechanism the muscle tissue is categorized into three parts namely the skeletal muscle, smooth muscle and the cardiac muscle. In these skeletal muscles the EMG is applied to study its behaviour, The skeletal muscles are then connected to bones and credited to providing the support and moving mechanism to the skeleton, Neurons are well associated with the skeletal muscle for its contraction which are called the motor neurons which is closely approached to the muscle tissues although not connected to it directly.

The human body is electrically neutral as a whole but it has charges which are equal in numbers and hence cancelling out effect as a whole.In the resting state the polarization of the nerve cell occurs due to the difference arises in ionic concentrations across the plasma membrane Changing the potential difference already existing between the intracellular and extracellular fluid cell membranes. In response to an external stimulus, a muscle fiber depolarizes as the signal propagates along its surface and the fiber twitches. This depolarization, followed by flow of ions, led to the generation of electric fields close to muscle fibre.

Applications of EMG

The numerous applications of electromyography (EMG) include diagnosing neuromuscular disease and determining the presence of dysfunctions or abnormalities in clinical practice, the rehabilitation of muscle action via EMG biofeedback, demonstrating kinesiology in anatomical studies, use in ergonomics as a tool for studying kinesiological muscle function related to posture and other biomechanical stress indicators, as well as a movement pattern identifier and a nervous system control parameter of the nervous system. [2]

Raw data from the sensor

The data acquired from the electrode is raw EMG data. It has a variety of noise signals and electrical disturbances. The typical amplitude range of an EMG signal is 0-10 mV (+5 to -5) prior to amplification. The electrical noise affecting the raw biosignal is listed below[3]:

1. Inherent noise in electronics equipment: All electronics equipment generate noise. This noise cannot be eliminated; using high quality electronic components can only reduce it.
2. Ambient noise: Electromagnetic radiation is the source of this kind of noise. The surfaces of our bodies are constantly inundated with electric-magnetic radiation and it is virtually impossible to avoid exposure to it on the surface of earth.
3. Motion artifact: When motion artifact is introduced to the system, the information is skewed. Motion artifact causes irregularities in the data. There are two main sources for motion artifacts: 1) electrode interface and 2) electrode cable. Motion artifacts can be reduced by proper design of the electronics circuitry and set-up.
4. Inherent instability of signal: The amplitude of EMG is random in nature. EMG signal is affected by the firing rate of the motor units, which, in most conditions, fire in the frequency region of 0 to 20 Hz. This kind of noise is considered as unwanted and the removal of the noise is important.

There is also power line noise disturbance at the 50Hz, which will have to be removed from the biosignal.

Signal description

The data that we have used is from www.emglab.net. We have used the R002 dataset. The data is a multi-channel EMG signal from moderate isometric contractions of tibialis anterior. The signals were recorded by two monopolar fine wires (inserted together, but with their recording

surfaces offset by about 2 mm) and a monopolar needle electrode inserted to the same depth at a point 0.5 cm away from the wires. [4]
We have used the data from the monopolar fine wires for our sensor instrumentation validation. The use of real world data is done to prepare a model as close to a real world sensor as possible.

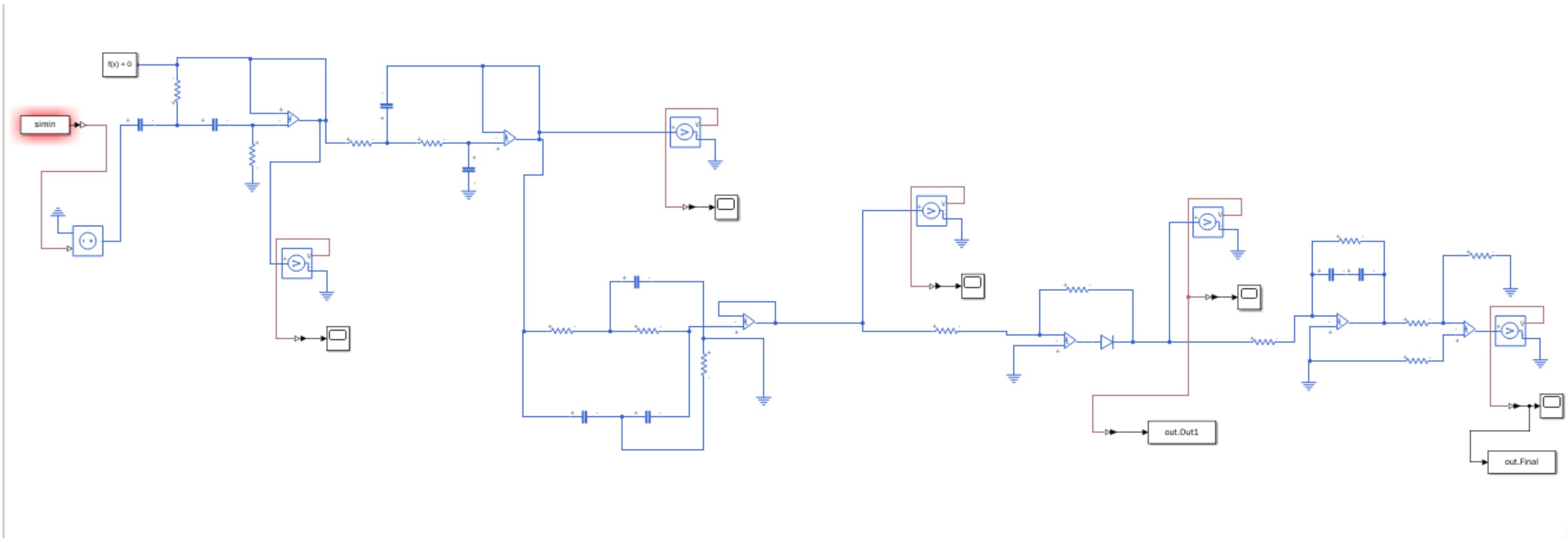
Instrumentation Requirements

The instrumentation requirements are:

- High Pass Filter
- Low Pass filter
- Twin T Notch Filter
- Half wave precision Rectification
- Smoothing by envelopment

Design Chapter

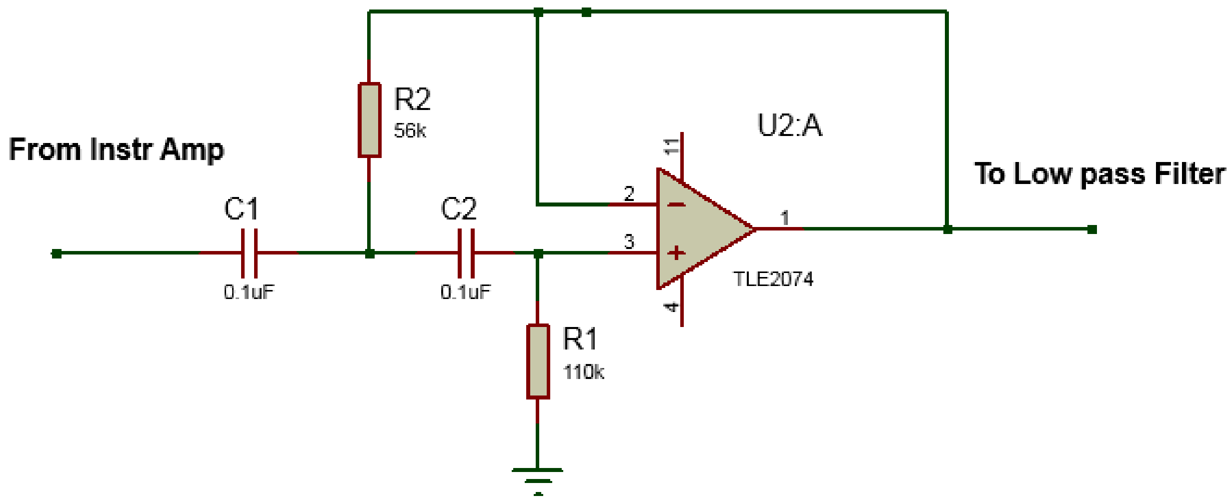
Circuit



This is a novel Simulink circuit that has been designed based on extensive literature review and knowledge acquired by the authors during the course BE503. The circuit models real world components to provide the instrumentation of a sensor that processes raw data from fine wire EMG electrodes. The simulink model of the circuit takes in the data from MATLAB and passes it through a High pass filter, Low pass filter, Twin T Notch filter, half wave precision rectification and smoothing by envelopment. The detailed circuit diagrams for each filter, description of the respective real-world Op-Amps, filter cutoffs and functionality is given in the block description. The frequency spectrum and other amplitude parameter plotting was done using a MATLAB code.

Block wise description

High Pass Filter



[5]

The passive components C1, R1, C2 and R2 form the second-order frequency-selective circuit.

Thus at low frequencies, capacitors C1 and C2 appear as open circuits, so the input signal is blocked resulting in no output. At higher frequencies, CA and CB appear to the sinusoidal input signal as short circuits, so the signal is buffered directly to the output.

The values for resistance and capacitance are already shown in the above figure. The op-amp which we have used is TLE2074. The specification for the Opamp is based on the TLE2074 datasheet. The specification is:

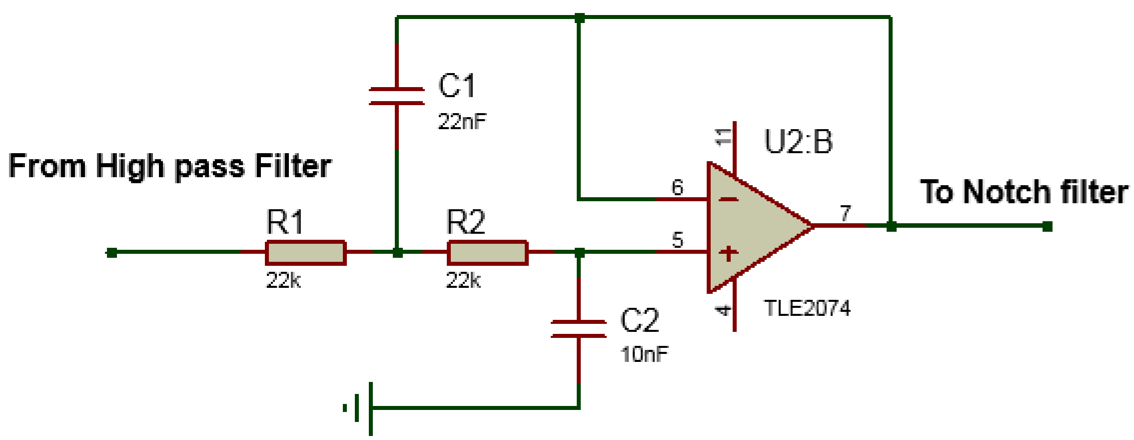
Gain, A:	1	
Input resistance, Rin:	1e13	Ohm
Output resistance, Rout:	80	Ohm
Minimum output, Vmin:	-15	V
Maximum output, Vmax:	15	V
Maximum slew rate, Vdot:	4e7	V/s
Bandwidth, f:	10	MHz
Initial output voltage, V0:	0	V

The cutoff frequency is given by:

$$fc = 1 / (2 * \pi * \sqrt{R1} * \sqrt{R2} * \sqrt{C1} * \sqrt{C2})$$

In our case, this gives the **cutoff frequency is around 20 Hz**.

Low Pass filter



The above design is of the second order low pass filter which we have used in our project. The values of different components are already shown in the figure and the values are chosen in order to get the desired value of cutoff frequency.

The frequency range below this cutoff are allowed to pass through the filter while those above this range are not allowed to pass.

The op-amp which we have used in this circuit is TLE2074. The specification for the Opamp is based on the TLE2074 datasheet. The specification is:

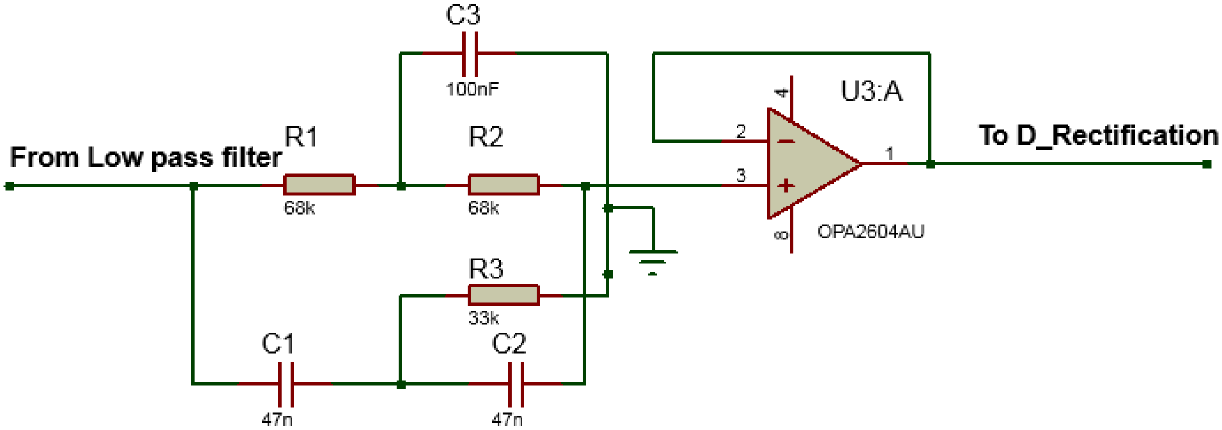
Gain, A:	1	
Input resistance, Rin:	1e13	Ohm
Output resistance, Rout:	80	Ohm
Minimum output, Vmin:	-15	V
Maximum output, Vmax:	15	V
Maximum slew rate, Vdot:	4e7	V/s
Bandwidth, f:	10	MHz
Initial output voltage, V0:	0	V

The cutoff frequency is given by:

$$fc = 1 / (2 * \pi * \sqrt{R1} * \sqrt{R2} * \sqrt{C1} * \sqrt{C2})$$

In our case, this gives the cutoff frequency around 488 Hz.

Twin T Notch Filter



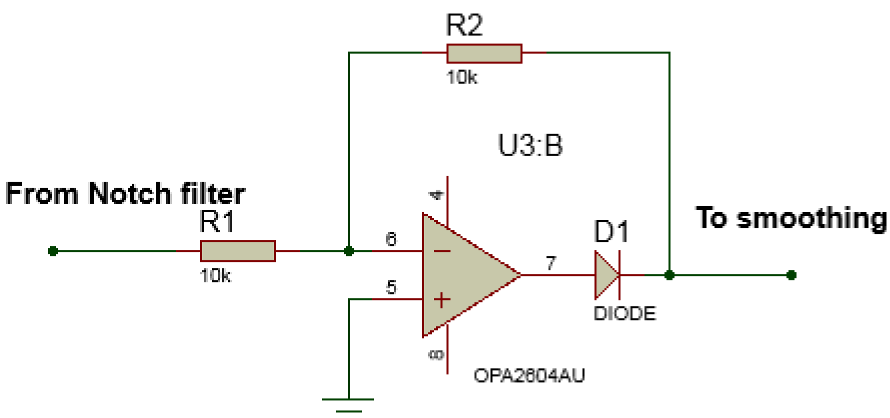
A notch filter is nothing but a narrow band-stop filter. If the stopband of band-stop filter is very narrow and highly attenuated over a few hertz, then that special type of band-stop filter is known as Notch filter. Since the stopband of notch filter is narrow up to a few Hz so the Notch filter is also known as narrow band stop filter in some cases. It is a highly selective form of band-stop filter which can be used to block a single or very small band of frequencies rather than the whole bandwidth of different frequencies. For obtaining a high level of attenuation and narrow notch, an operational amplifier is used to design a single Op-Amp twin-T notch filter circuit. The single Op-Amp twin-T notch filter circuit used is shown in the above figure.

In a typical twin T notch configuration, $R1 = R2 = 2 * R3$ and $C3 = 2 * C1 = 2 * C2$ Their values are shown in the figure itself. Op-amp used in this circuit is OPA2604AU. The specification for the Opamp is based on the OPA2604AU datasheet. The specification is:

Gain, A:	1e3	
Input resistance, Rin:	10	Ohm
Output resistance, Rout:	25	Ohm
Minimum output, Vmin:	-15	V
Maximum output, Vmax:	15	V
Maximum slew rate, Vdot:	2.5e7	V/s
Bandwidth, f:	20	MHz
Initial output voltage, V0:	0	V

The notch frequency in this case is given by $1 / (4 * \pi * R3 * C1)$, which will be around **50 Hz**.

Double Recification



The above diagram shows a very basic half wave precision rectifier with an op-amp and a diode. The values for resistances are already shown in the figure. As we can see, this is in inverting configuration and therefore gain is given:

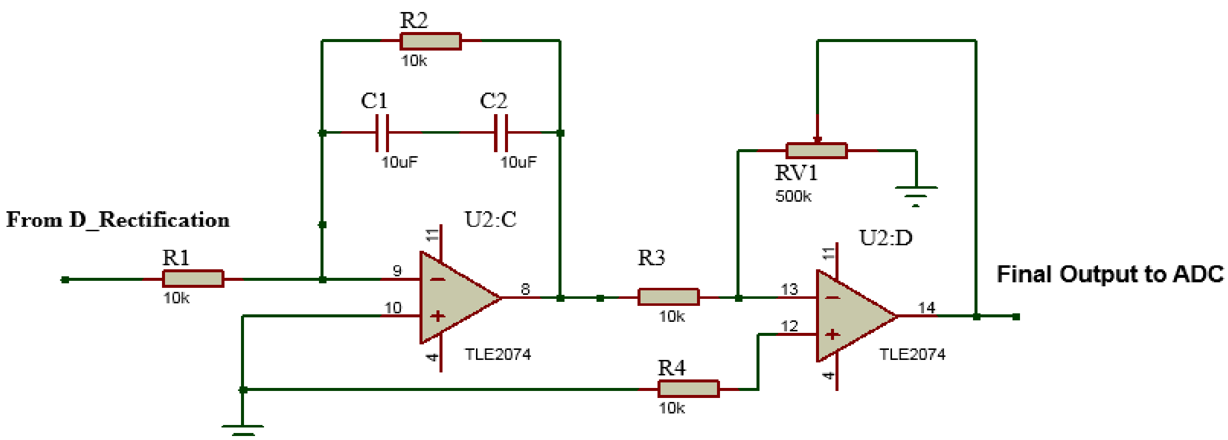
$$A = - R2/R1$$

This gives us a **gain of -1** in our case.

Op-amp used in this circuit is OPA2604AU. The specification for the Opamp is based on the OPA2604AU datasheet. The specification is:

Gain, A:	1e3	
Input resistance, Rin:	10	Ohm
Output resistance, Rout:	25	Ohm
Minimum output, Vmin:	-15	V
Maximum output, Vmax:	15	V
Maximum slew rate, Vdot:	2.5e7	V/s
Bandwidth, f:	20	MHz
Initial output voltage, V0:	0	V

Smoothing



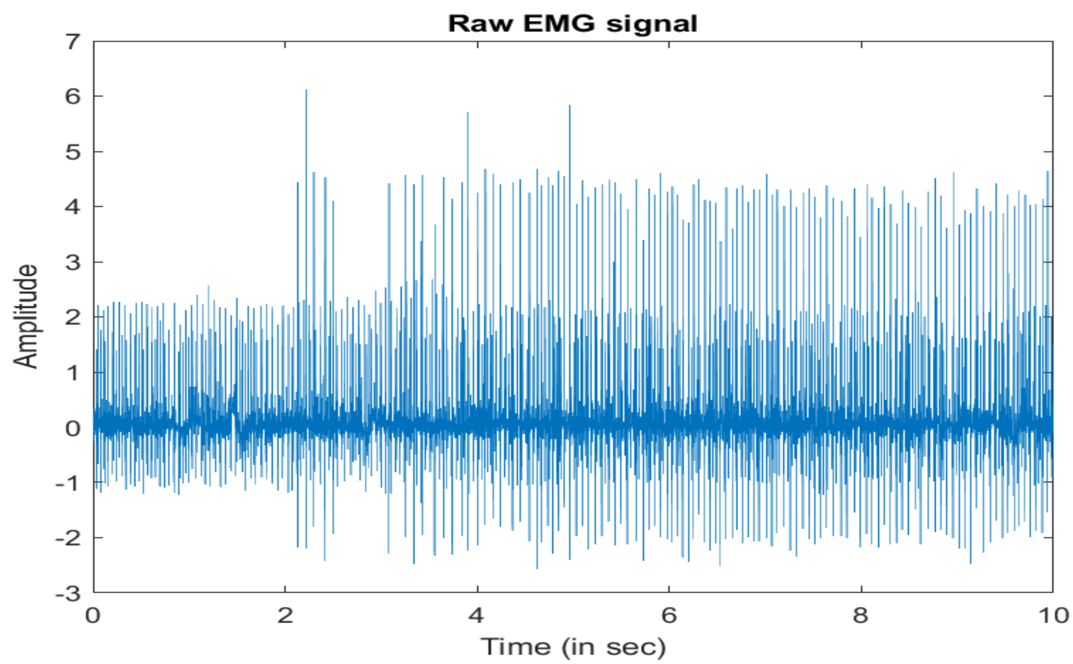
This is the final smoothing circuit after which we will be getting our final signal.

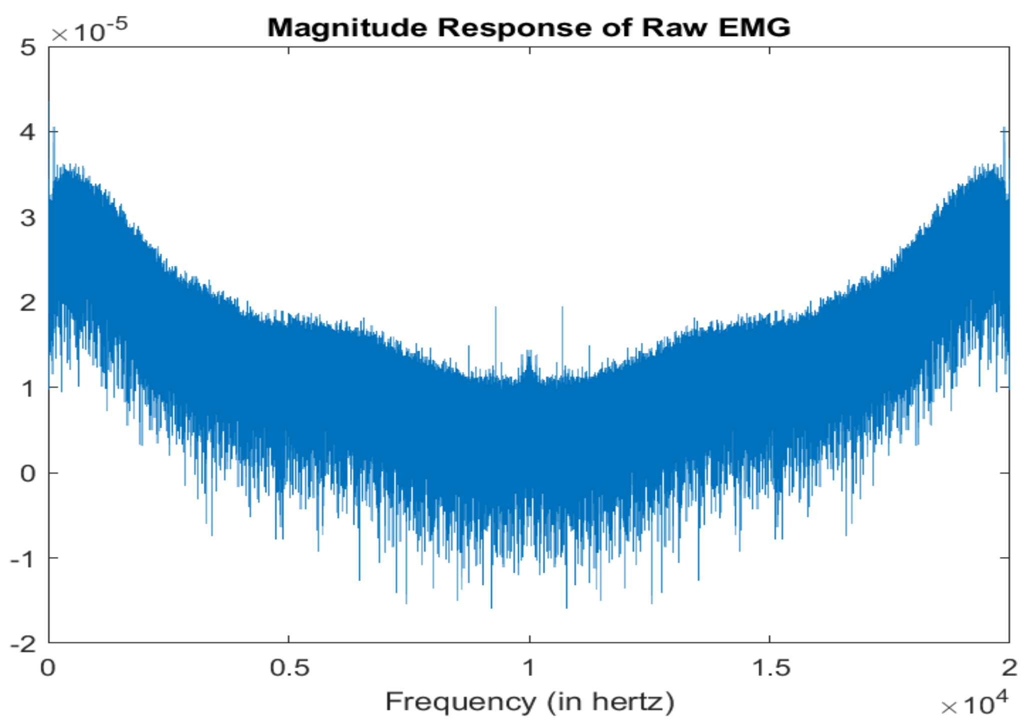
The values for resistors and capacitances are already shown in the figure. Op-amp used in this circuit is TLE2074. The specification for the Opamp is based on the TLE2074 datasheet. The specification is:

Gain, A:	1	
Input resistance, Rin:	1e13	Ohm
Output resistance, Rout:	80	Ohm
Minimum output, Vmin:	-15	V
Maximum output, Vmax:	15	V
Maximum slew rate, Vdot:	4e7	V/s
Bandwidth, f:	10	MHz
Initial output voltage, V0:	0	V

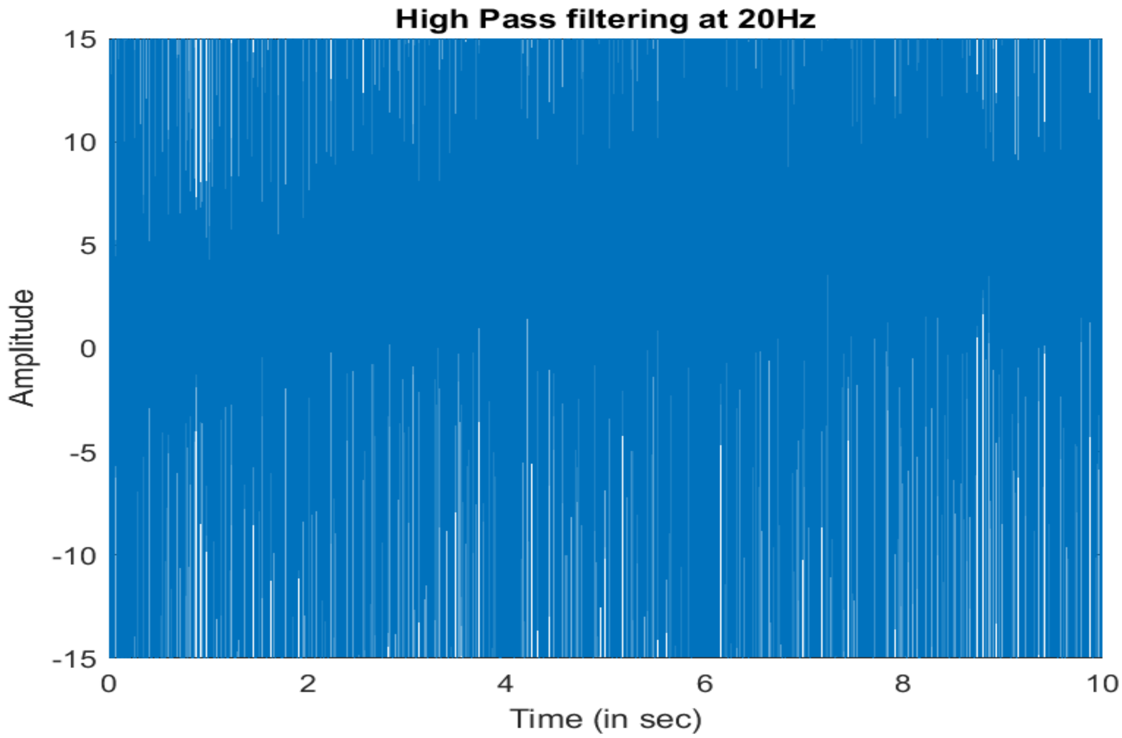
Results Chapter

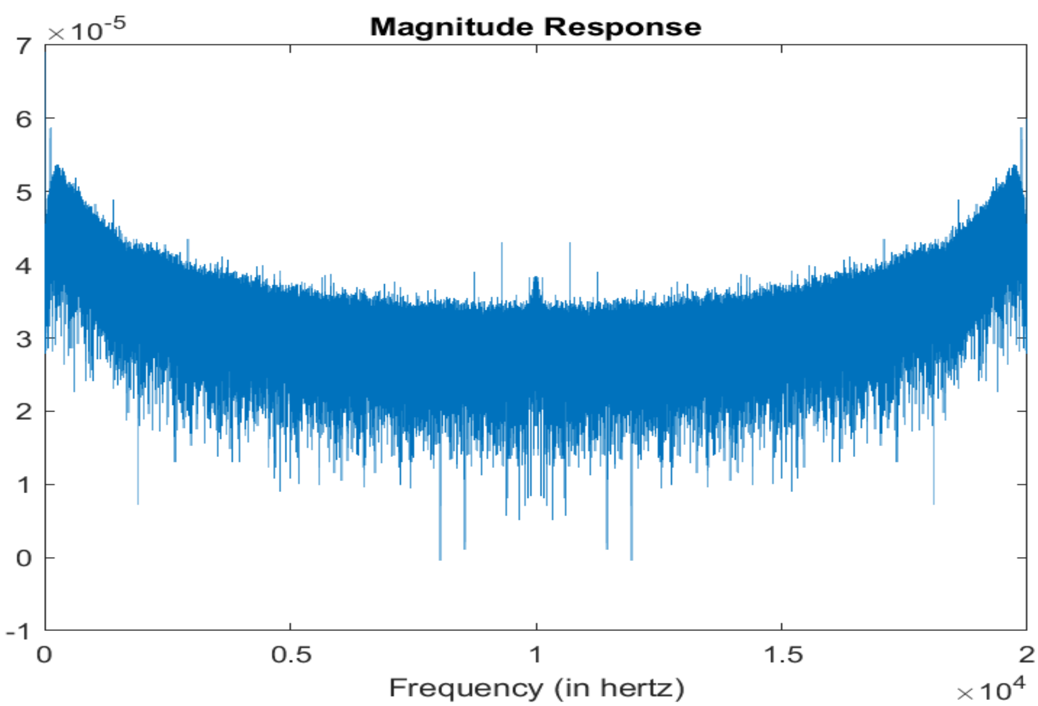
- <u>Raw EMG signal</u>



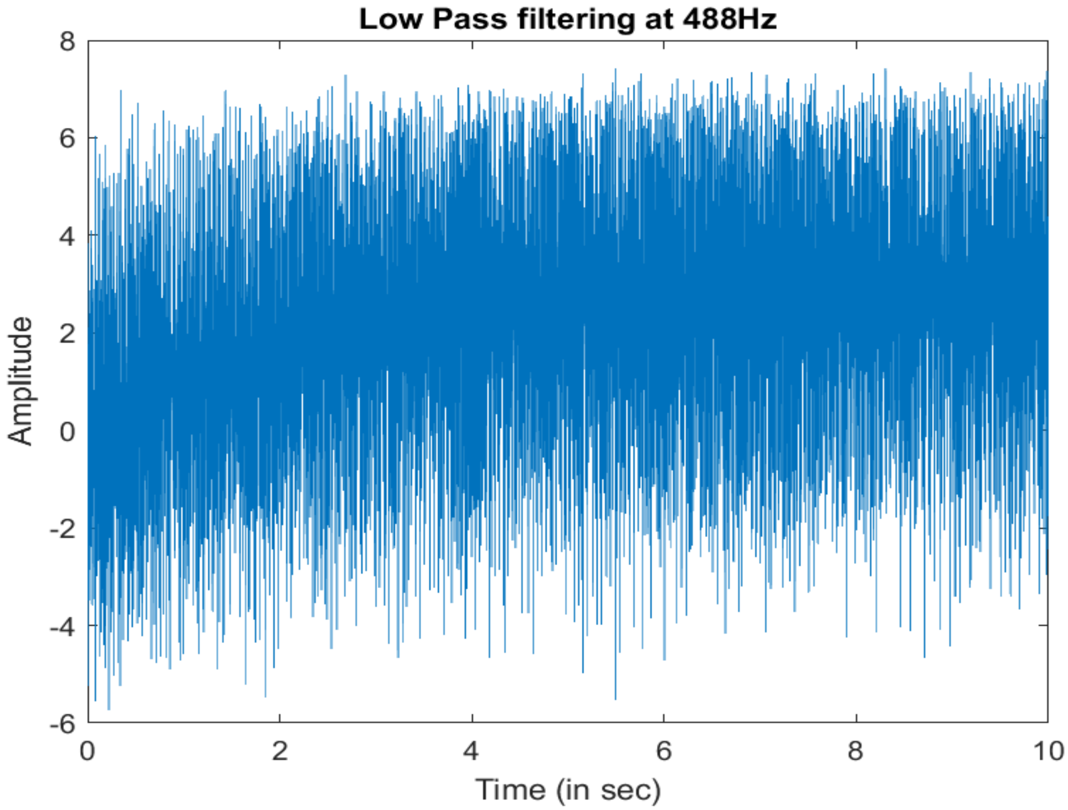


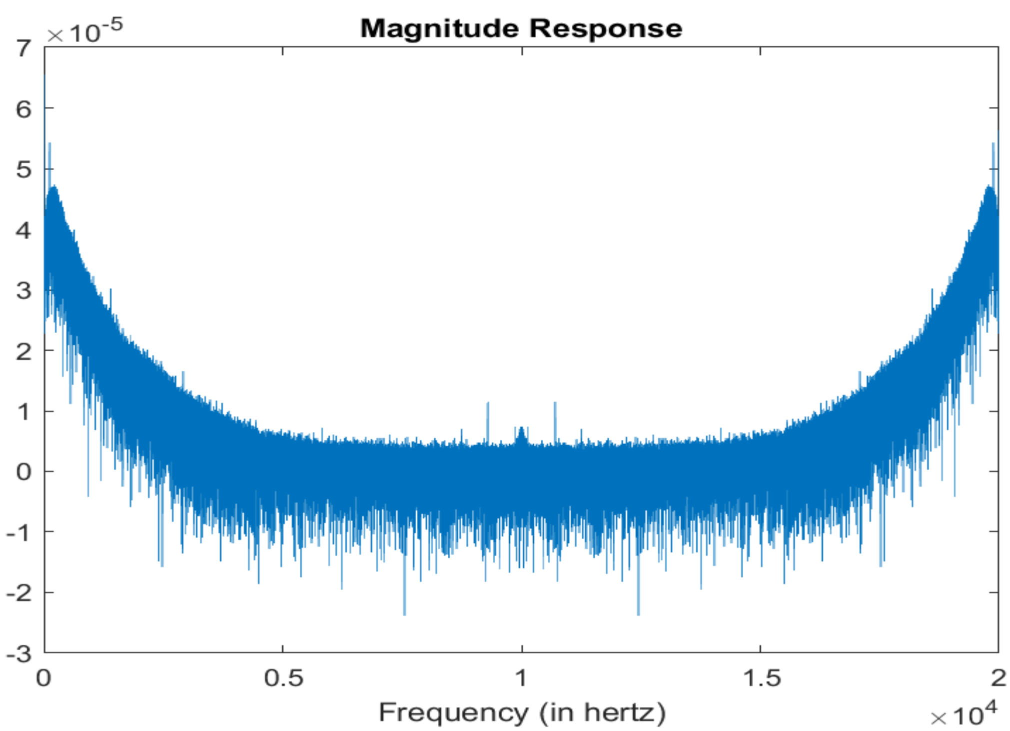
- After High Pass Filtering at 20 Hz



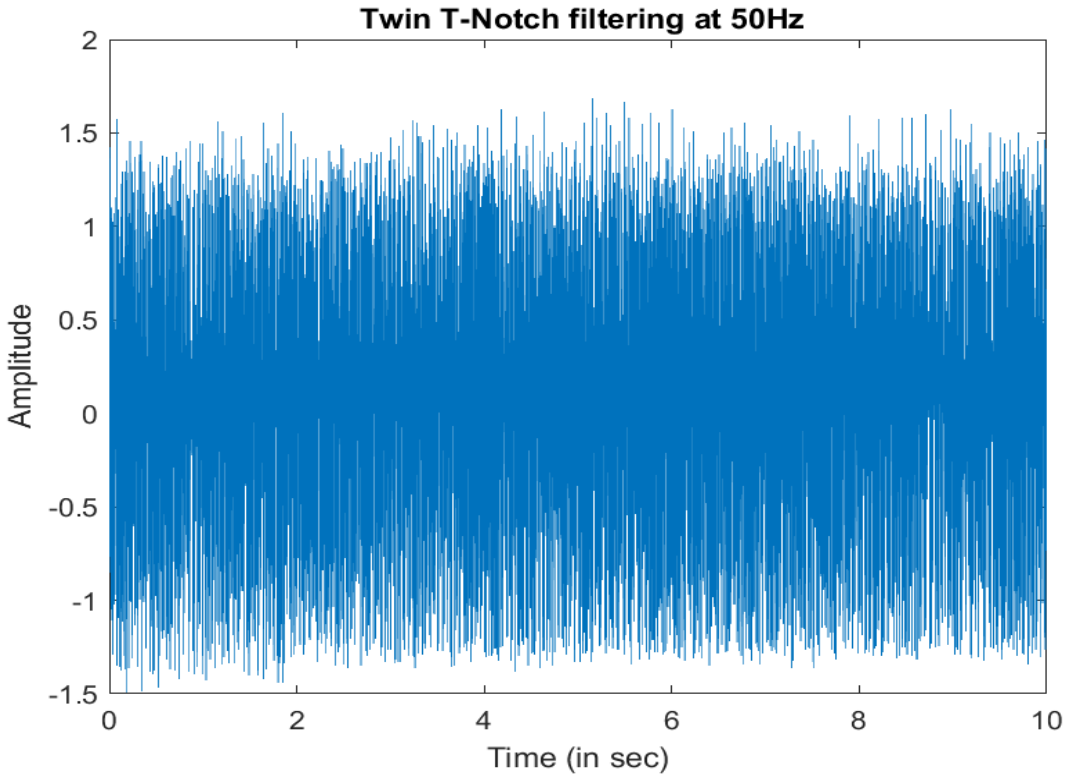


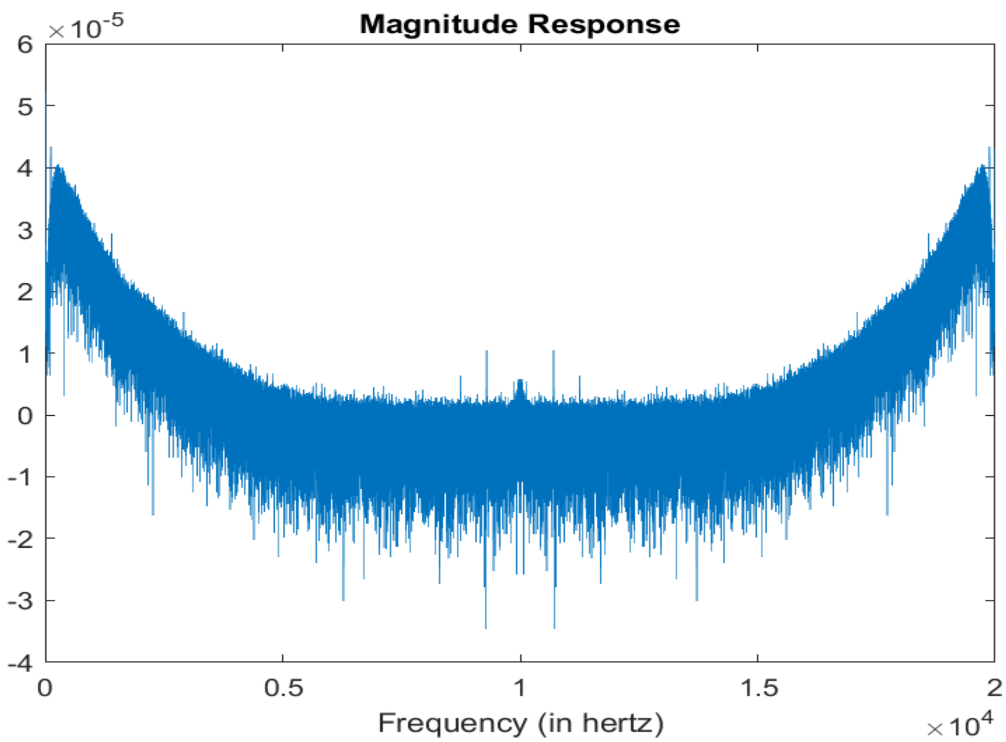
- After Low pass filtering at 488 Hz



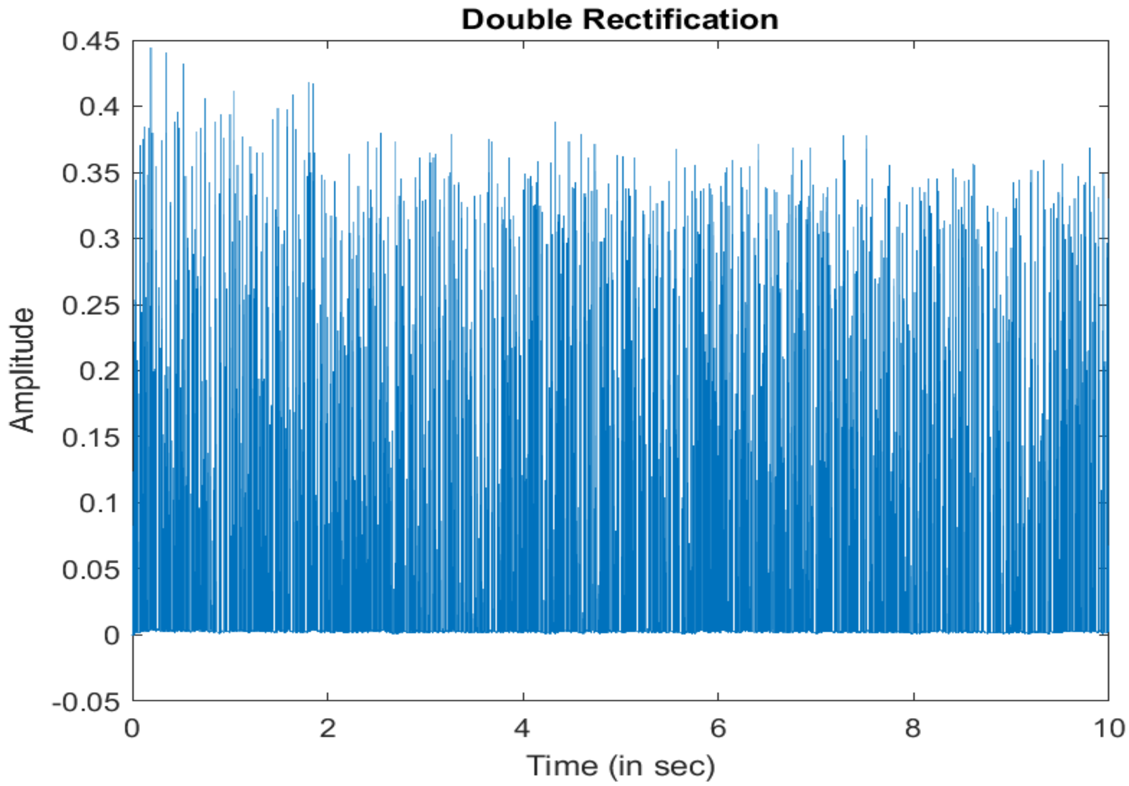


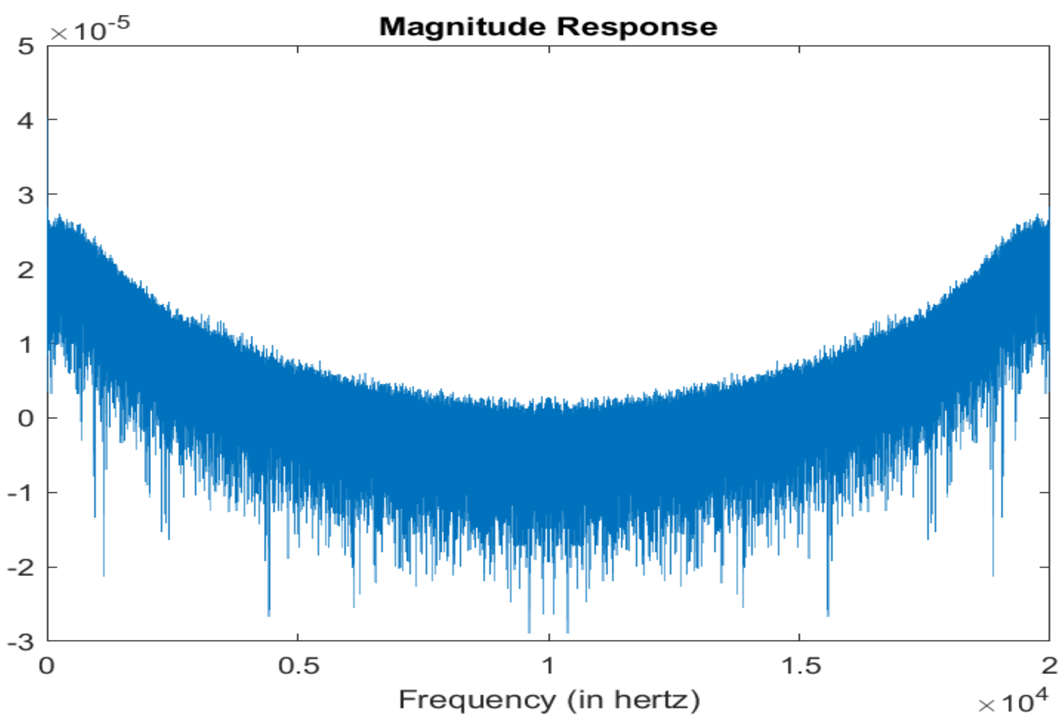
- After Twin T Notch filtering at 50 Hz



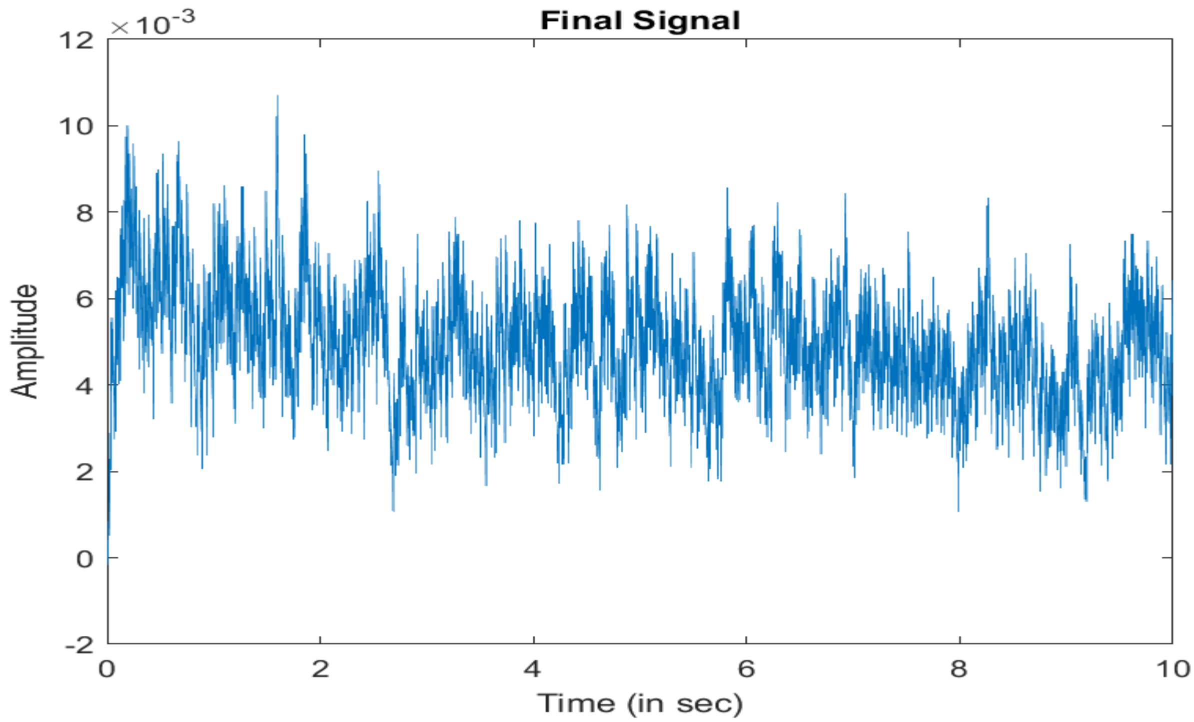


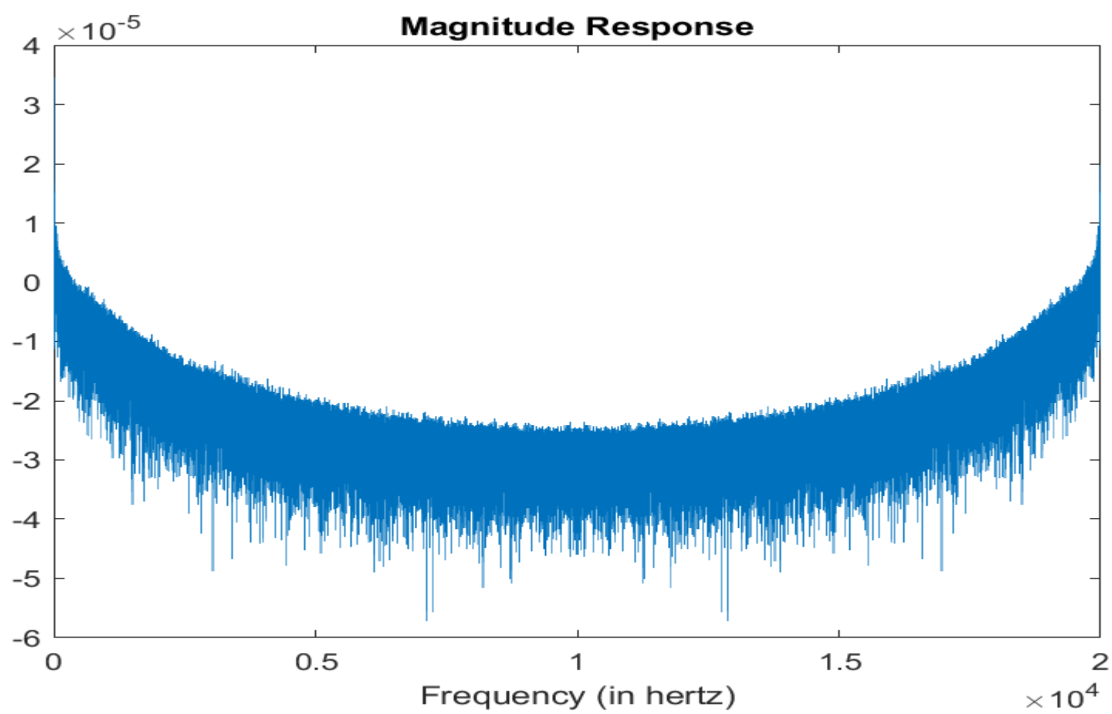
- After Half-wave precision rectifier





- Final Signal after Smoothning





Inference

A broader inference from the results from the beginning point to the end would be that there is significant improvement in the noise-removal and clarity of the data from the beginning to the end point.

At each step the instrumentation is displaying the desired result in the data. For each step we have plotted the amplitude of the EMG signal vs time and the 20*log10(abs(FFT(data))) vs frequency. After the high pass filter application we observe that the EMG data is between -15 to 15. We also observe the filtering of the low frequency parts of the spectra. After the low pass filter application we observe that the EMG data is between -6 to 6. We also observe the filtering of the spectra and a change in the range of the y axis values. After the notch filter application we observe that the EMG data is between -1.5 to 1.5. We also observe a sharp dip in the spectra at 50 Hz. After half wave precision rectification only positive values of the signal remain and they are between 0 to 0.45. The FFT spectrum becomes smoother.

The final signal consists of 200,000 data points and is representative of a real EMG signal. The FFT is smooth and all the noise components have been filtered. The range of the final signal is between 0-10 mV which is as postulated in the theoretical section of this report. Signal processing techniques can be applied to the final signal data to generate further inferences or for prosthesis control.

Thus our model is able to emulate a real world EMG. The data is visually emulating real world signals as well. This is a significant achievement as the Simulink circuit models real world circuit components and can easily be fabricated and would be able to achieve similar results.

Author Contributions

Model Instrumentation and Design: AG,SM
MATLAB code:AG,SM
Literature review: AG,SM
Abstract: SS
Theoretical Background: AG,SM,SS
Design Chapter:AG, SM
Results: AG,SM
Report Design and Formatting: AG, SM

References

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